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Expansion of avocado agricultural frontier in the avocado belt of Michoacán, México, 1974-2024☆

Expansión de la frontera agrícola del aguacate en la franja aguacatera de Michoacán, México, 1974-2024

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Abstract

This paper analyzes fifty years of expansion of the avocado agricultural frontier in the ´avocado belt´ of Michoacán, a key region because Mexico is the world's leading avocado producer and this state concentrates most of the national production. During this period, the avocado frontier has expanded at different rates, but unfortunately, over the last two decades it has advanced into areas of forest cover, generating severe environmental problems. The history of this expansion is shown through a series of six maps produced by visual interpretation of aerial photographs and very high-resolution satellite images for the years 1974, 1995, 2007, 2011, 2018 and 2024. All maps were initially produced at scales between 1:5,000 and 1:20,000, and were later brought to a common scale of 1:20,000 through cartographic generalization, in order to allow a consistent visual comparison.

Keywords: avocado, expansion of agricultural frontier, Michoacán

Resumen

Este trabajo analiza 50 años de expansión de la frontera agrícola del aguacate en la ´franja aguacatera´ de Michoacán, una región clave porque México es el principal productor mundial de aguacate y este estado concentra la mayor parte de la producción nacional. Durante este período, la frontera agrícola del aguacate se ha expandido a diferentes ritmos, pero desafortunadamente, en las dos últimas décadas lo ha hecho sobre áreas de cubierta forestal, lo que ha generado problemas ambientales severos. La historia de esta expansión se muestra a través de una serie de seis mapas elaborados mediante interpretación visual de fotografías aéreas e imágenes de satélite de muy alta resolución para los años 1974, 1995, 2007, 2011, 2018 y 2024. Todos los mapas fueron inicialmente producidos a escalas entre 1:5,000 y 1:20,000, y finalmente llevados a una escala común de 1:20,000 mediante generalización cartográfica, con el fin de uniformizar su comparación visual.

Palabras clave: aguacate, expansión de la frontera agrícola, Michoacán

1. Introduction

Avocado is of great economic importance for Mexico, but especially for the state of Michoacán, being the only Mexican state allowed to export avocados to the U.S. (Cho, 2020). The state produces eight out of ten Mexican avocados, and five out of ten avocados produced globally. Its regional economy is strongly dependent on avocado farming, with a market value of around US $2.5 billion a year (World Economic Forum, 2020).

Unfortunately, this economic bonanza has brought about se-

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vere environmental and social problems in the territory where avocado is being produced. A recent report on these problems published by Climate Rights International (CRI, 2023) accounts for the environmental costs of intensive production, aggravated by social conflicts due to the presence of organized crime in some parts of the production chain.

Among the most critical environmental problems is deforestation. The loss of forest land due to the introduction of avocado started to become an increasing concern with the opening of the U.S. market (Morales et al., 2012). It was not until 2024 that measures were implemented to monitor and report this harmful activity to the forest cover and the environment more effectively. On one hand, the Government of the State of Michoacán built and launched a monitoring system for forest cover impacts called 'Forest Guardian' (Guardián Forestal, 2024) which performs daily satellite surveillance actions in forest cover areas. Based on this information, it has promoted complaints against those producers responsible for the illegal change of land use, specifically for replacing forest cover with avocado orchards.

Internationally, measures have also begun to be implemented to restrict the export of avocados grown in orchards that have affected forest cover. Following the study by Climate Rights International, the United States Senate has taken action to ban the importation of avocados grown under those conditions.

Likewise, the Commission for Environmental Cooperation, an organization created under the Agreement on Environmental Cooperation among the Governments of the United States of America, the United Mexican States, and Canada, filed a complaint in 2023 (CEC, 2023a) regarding environmental damage caused by the expansion of avocado cultivation. This complaint received a mild response from the Government of Mexico, which requested the creation of a factual record but took no further action, despite acknowledging that it had previously received similar complaints (CEC, 2023b).

Additionally, it is foreseeable that the European Union, thro ugh its European Union Deforestation Regulation program, will soon consider avocado as one of the products subject to this regulation. This regulation is particularly important because it not only considers applying restrictive measures to the importation of agricultural products that have caused deforestation but also to those that cause forest degradation (European Commission, 2023), which is also the case for avocado.

The expansion and advance of avocado cultivation over forest cover continued at an accelerated pace over the last two decades and up to the present. Since two spatially comprehensive studies conducted in 2007-2012 (Morales and Cuevas, 2011, Morales et al., 2012) showed a significant increase in the avocado frontier, there have been no other impact studies on forest covering the entire avocado region. However, some recent local studies (España Boquera et al., 2022; Benítez Franco, 2023; CONANP, 2023; Denvir, 2023; Ramírez et al., 2024; López Sánchez, 2024; Subercaseaux Ugarte et al., 2025) and numerous national and international press reports have documented this trend.

2. Methods

Despite growing concerns about the environmental problems caused by the expansion of avocado cultivation, very few efforts have been made to accurately map the agricultural frontier, and its evolution, in its entirety across the state of Michoacán. The maps presented here represent several years of ongoing efforts to provide the best possible account of this expansion. They are the unpublished results of research projects carried out by our work group from 2007 to 2024 (Morales and Cuevas, 2011, Morales et al., 2012, Morales et al., 2024). These maps accurately depict the location of avocado orchards in the years 1974, 1995, 2007, 2011, 2018, and 2024 in the region known as the 'avocado belt'.

The method to create these maps is similar in all cases: visual interpretation of photographs or satellite imagery. At the beginning of our investigations, we tried using semiautomatic methods with both supervised and unsupervised algorithms. We found that, on one hand, many orchards could not be correctly identified because they corresponded to young individuals, and these areas were often confused with barren land or grassland. On the other hand, for those orchards that were correctly identified, the vector geometry derived from the raster classification was too intricate and required extensive cleaning and manual work to match the resulting polygon lines with the true geometry of the orchards' boundaries.

Hence, the identification and digitization of orchard boundaries proceeded manually. To standardize the procedure, all members of the workforce were trained to follow specific criteria to identify, validate, and digitize avocado orchards. This ensured consistency across different interpreters and the necessary accuracy. Onscreen digitization was applied to all images to obtain the boundaries of the avocado frontier.

2.1. Area of study

The first task is to outline the boundaries of the area of interest. To achieve this, previous works delimiting the agricultural frontier of avocado were considered, including studies conducted by government agencies, associations of producers, and academic institutions (Morales Manilla et al., 2012). These previous delineations are all incomplete and do not indicate all the areas currently under avocado cultivation. Therefore, a visual interpretation of images from the Google Earth Pro platform was carried out to approximately delimit the actual area (Figure 1).

The extension of this region spans 1,618,000 hectares, including forest land, areas under avocado cultivation, land under cultivation with other crops and shrubland / grassland.

2.2. Procedure

The preparation of the avocado frontier maps for the years 1974 and 1995 was done by visually interpreting black-and-white aerial photographs. For the first year, the individual printed photographs from an aerial flight were first scanned and then georeferenced. We then employed Agisoft Photoscan (currently

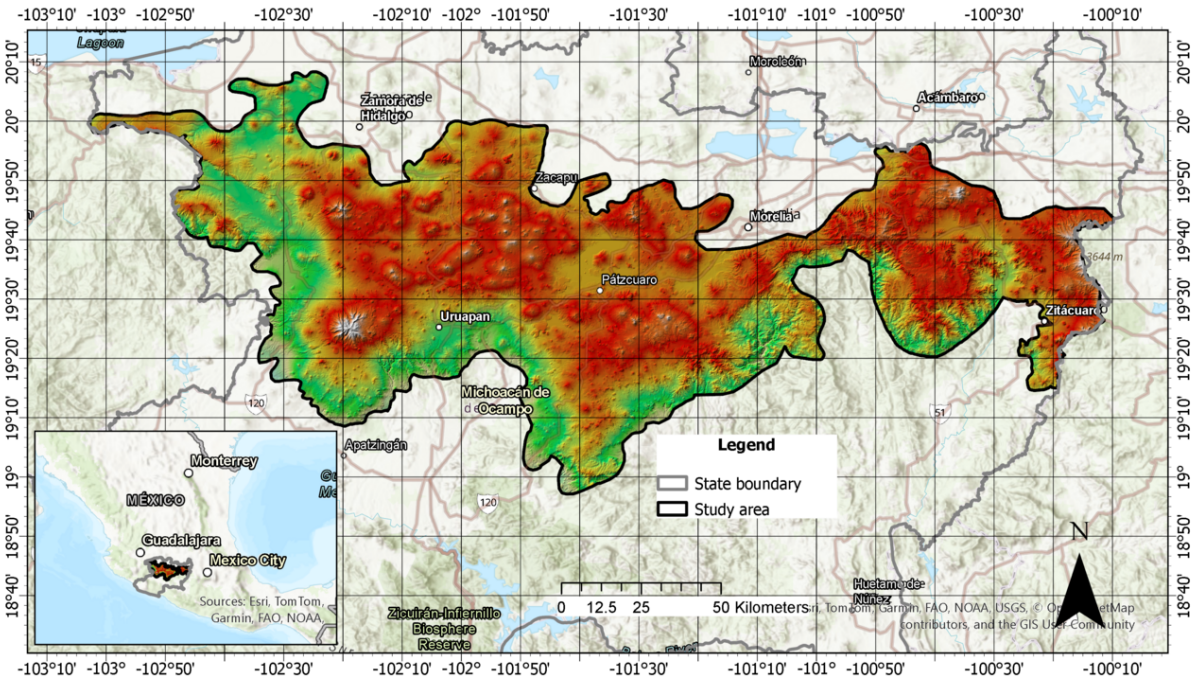

Figure 1. Area of study. / Figura 1. Área de estudio

Metashape) to photogrammetrically process them to create an orthomosaic. Since at that time the extension of avocado cultivation was restricted to a few areas within the study area, it was not necessary to create an orthomosaic of the entire area (Figure 2).

For the second year, existing black-and-white orthomosaics produced by the National Institute of Statistics and Geography (INEGI, 1995) were used (Figure 3). In both cases, the visual quality of the orthomosaics presented differences in brightness that occasionally made it difficult to identify avocado orchards. These areas of uncertainty had to be validated using more recent satellite imagery, yet there remained problems in identifying young orchards, which caused confusion with lemon and mango. For both data sets, the scale of the derived maps is 1:20,000.

The next year in the map series, 2007, required the use of SPOT imagery. We used a combination of false color composite sharpened with the panchromatic band to improve identification. With this resolution it was possible to bring the scale of mapping to 1:10,000 (Figure 4). Given the still relative low resolution of SPOT multispectral imagery, the problem of confusing young orchards with barren land or grassland persisted in the results for this year. This caused an underestimation in the amount of area planted with avocado, but it was possible to reduce confusion with lemon and mango orchards thanks to the use of a false color composite with the infrared band.

For the year 2011, we used true color composites of Worldview-2 imagery with a resolution of 50 cm. This allowed for much better identification of orchards, including the most recent ones. With this resolution, mapping was done at a scale of 1:5,000 (Figure 5). Additionally, area underestimation was kept to a minimum, and confusion with lemon and mango orchards was drastically reduced.

Figure 2. Sample of the aerial photographs used in the identification of avocado orchards in 1974. / Figura 2. Muestra de las fotografías aéreas utilizadas para la identificación de huertas de aguacate en 1974.

Lastly, maps of the years 2018 and 2024 were prepared with the same visual interpretation procedure and at the same scale as the previous one. In these cases, we used very high-

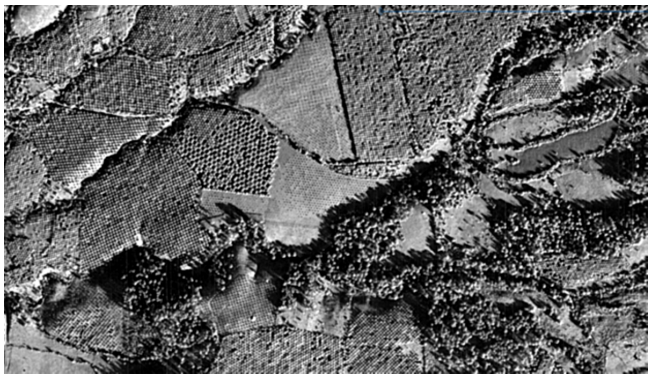

Figure 3. Sample of the INEGI's orthomosaic used in the identification of avocado orchards in 1995. / Figura 3. Muestra del ortomosaico del INEGI utilizado para la identificación de huertas de aguacate en 1995.

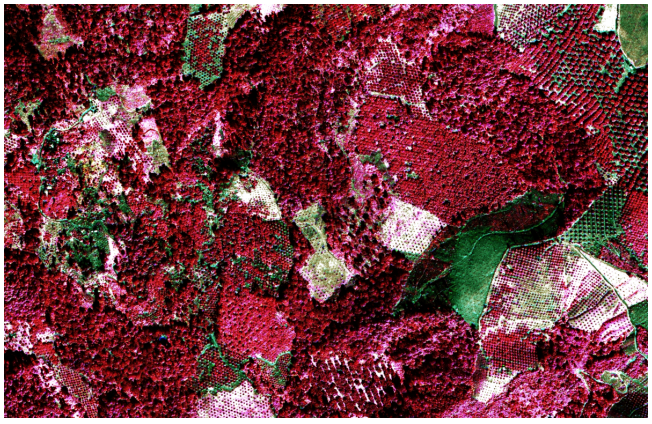

Figure 4. Sample of SPOT imagery used in the identification of avocado orchards in 2007. The use of the infrared band in the false color composite facilitated the discrimination between avocado orchards and forest cover. / Figura 4. Muestra de la imagen SPOT utilizada para la identificación de huertas de aguacate en 2007. El uso de la banda infrarroja en la composición de color falso facilitó la discriminación entre las huertas de aguacate y la cobertura forestal.

resolution imagery available on the platforms ESRI Wayback and Google Earth, with the advantage of having several dates of imagery within those years, and with resolutions up to 30 cm for some areas (Figure 6).

Once the maps corresponding to each year of interest were prepared, a procedure of cartographic generalization was applied to all maps to bring them to the common scale of 1:20,000 (Figure 7). This was done with ESRI's ArcGIS Pro software. We also used this platform to prepare web maps and the interactive visualization version accompanying this document. The six maps are consolidated in one single map (Figure 8) which can be interactively explored at the following address: https://arcg.is/0vmmGP

3. Results

The maps we prepared and present here show that the expansion of the agricultural frontier of avocado in the state of

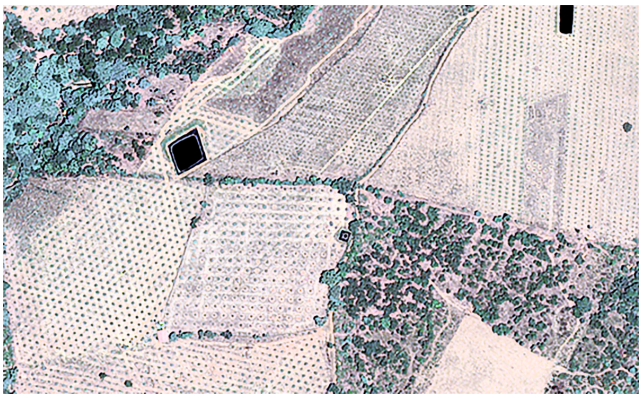

Figure 5. Sample of Worldview 2 imagery used in the identification of avocado orchards in 2011. The very high resolution facilitated the discrimination between avocado orchards and grassland, particularly in areas with young orchards. / Figura 5. Muestra de la imagen WorldView-2 utilizada para la identificación de huertas de aguacate en 2011. La muy alta resolución facilitó la discriminación entre las huertas de aguacate y los pastizales, particularmente en zonas con huertas jóvenes.

Michoacán has evolved through at least two phases of land use change. It was found that during the period 1974-1995, the expansion of avocado accounted for less than 72,000 hectares, with an annual increase of 2,166 hectares per year. This changed rapidly in the following years, and by 2007, the extension of avocado was about 112,725 hectares, representing an annual rate of 4,515 hectares per year, more than twice the previous rate. This increased dramatically by 2011, with an annual rate of 10,073 hectares, accounting for an extension of 153,018 hectares. Since then, the expansion has continued to increase to 214,845 hectares in 2018 and 266,109 hectares in 2024, with slightly lower rates of increase (Table 1), but still high enough to create concerns about the sustainability of avocado cultivation in the region.

Year	Hectares	Anual rate hectares/year
1974	13,045	-
1995	58,545	2,166
2007	112,725	4,515
2011	153,018	10,073
2018	214,845	8,832
2024	266,109	8,544

Table 1. Avocado expansion during the period 1974-2024 in the avocado belt of Michoacán, México. / Tabla 1. Expansión del aguacate durante el período 1974-2024 en el cinturón aguacatero de Michoacán, México.

It must be mentioned that commission errors in the final maps remain, mostly due to the confusion of avocado orchards with orchards of similar produce, like mango and lemon, especially in the border region of the study area. However, error levels in the last 3 maps have been kept to less than 1% through field verification. Omission errors are higher, but still less than

5%, particularly in the earlier maps, where the quality of black-and-white aerial photographs was not up to the standard of later satellite imagery, making it difficult to differentiate grasslands from young orchards.

Figure 6. Sample of ESRI's Wayback imagery used in the identification of avocado orchards in 2018-2023. The area depicted is the same as that shown in Figure 5. / Figura 6. Muestra de las imágenes de Wayback de ESRI utilizadas en la identificación de huertas de aguacate en 2018-2023. El área representada es la misma que se muestra en la Figura 5.

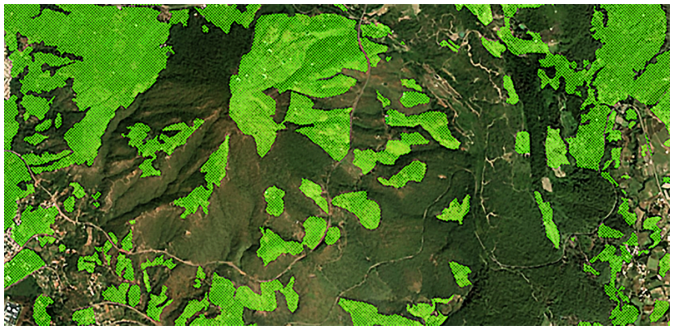

Figure 7. Cartographic representation of avocado orchards at 1:20,000. / Figura 7. Representación cartográfica de huertos de aguacate a 1:20,000.

4. Conclusions

From the maps, it can be readily observed that, in 50 years of cultivation, avocado orchards have experienced an ever-increasing expansion in the so called 'avocado belt of Michoacán, Market prices, lack of official and private regulations for the expansion, ineffectual protection of forest lands, and the presence of organized crime have been the main responsible of such accelerated growing.

Although from an economic point of view, this growth has represented an opportunity for development, this unregulated expansion has brought about severe environmental problems such as deforestation, loss of biodiversity, water scarcity, soil and water pollution and related impacts on public health. Also, land and social conflicts are now a growing concern, particularly because these have caused violence and safety issues in the region.

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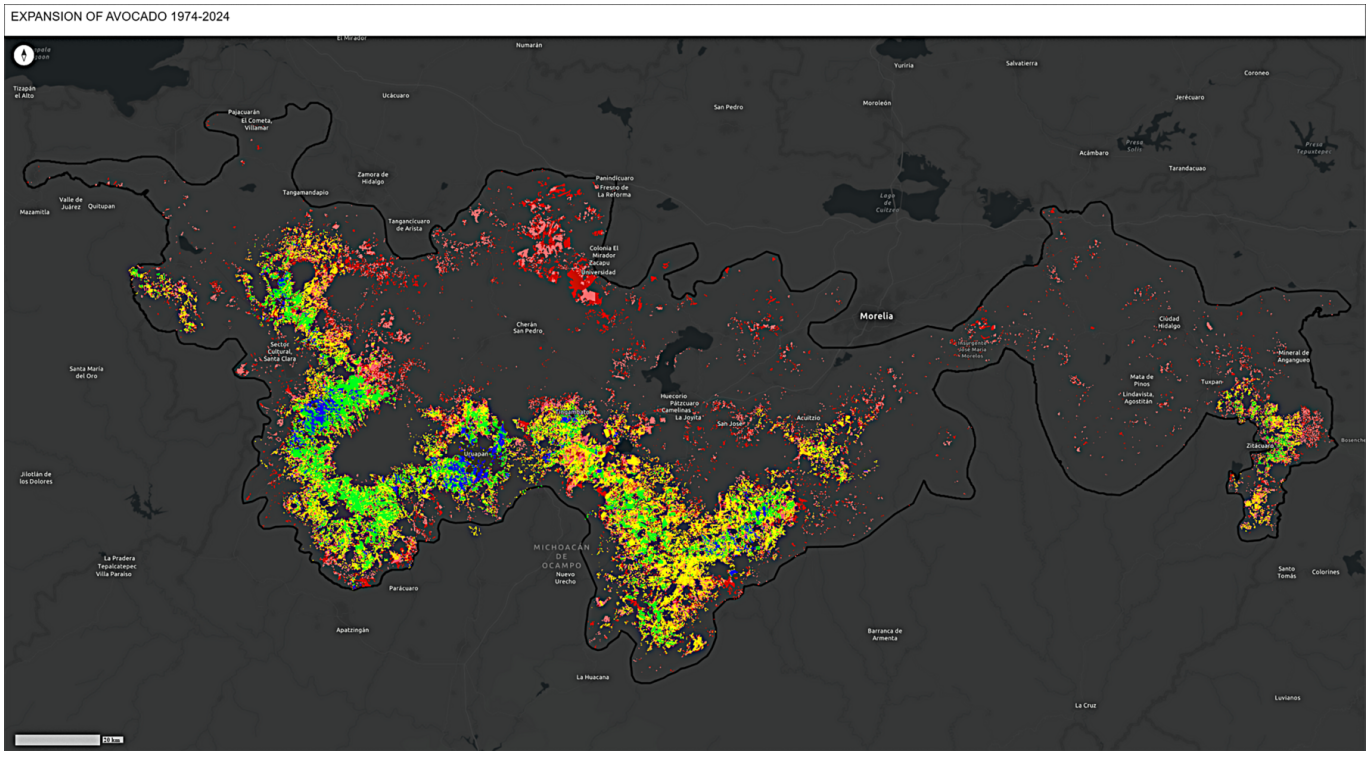

Figure 8. Evolution of the expansion of avocado in Michoacán, México, 1974 – 2024. / Figura 8. Evolución de la expansión del aguacate en Michoacán, México, 1974 – 2024.

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